Sulfur in Railway Elements

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Summary
The article presents the influence of sulfur as a harmful chemical element in railway elements working under load. The Baumann test shows the segregation of sulfur in the cross-section of the wheelset axle pivot, rail, wheel tyre and coupling elements. The tests were carried out in accordance with the standards PN-87/H-05414, ISO 4968:1979, PN EN 13674-1 + A1:2017, PN EN 13261: 2011, PN-84/H-84027/06, PN-EN 10083-3: 2006 and PN-EN 15566:2016-11, which require the determination of sulfur content and its distribution in those elements.

Keywords: sulfur, Baumann test, railway elements

1. Introduction

Elements of railway permanent way and rolling stock should be made of material with appropriate quality in terms of durability, due to the necessity to provide safety in railway transport. Because of the fact that sulfur adversely affects the properties of materials, there is a need to test sulfur segregation, especially in loaded rolling stock elements.

Sulfur is a chemical element present in all grades of steel. Sulfur content in steel is regulated during melting of the steel by adding calcium compounds, mainly in the form of dolomite (calcium carbonate $CaCO_3$ and magnesium carbonate $MgCO_3$), and also during out-of-furnace processing in the form of granulated CaC_2, Mg, CaSi, and Na_2CO_3, which are blown into steel by means of a carrier, which is an inert gas. During melting, sulfur forms chemical compounds with manganese in the form of MnS and its variations [2]. These compounds, called non-metallic inclusions, adversely affect steel strength in the case of sulfur content over 0.03%. One exception is free-machining steel, to which sulfur is added during casting of the steel, up to values exceeding 0.050%, to improve machinability during mechanical working, thanks to increasing chips fragility.

Moreover, a beneficial influence of sulfur on the functional properties of chosen products can be noticed on rolling bearings [1, 4]. In this case, the sulfur effect comes down to partial elimination of rolling friction between co-operating bearing elements, similar to the effect of lubrication. At the same time, sulfur compounds ductility contributes to structural stress relaxation in elements of machine parts, which are subject to heat treatment, and from which high hardness over 60 HRC is required.

Sulfur content in railway ready-for-use products is at a maximum of 0.030%, or should be consistent with the requirements of respective standards or reference documents for respective products. These standards define the permissible sulfur content and its distribution on the intersection of the element, in the form of patterns of Baumann prints with assigned qualification depending on the sulfur density and distribution on the cross-section of the tested elements. Control and classification are performed by comparing the obtained Baumann prints of the tested element with comparative patterns contained in appropriate standards or reference documents, according to which products intended for railway applications are produced and tested.

A sulfur segregation test on the cross-section of products is performed in accordance with the description of patterns given by the standards PN-87/H-04514 [6] and ISO 4968:1979 [3] or in accordance with factory procedures.

2. Material for test

The subject of the sulfur segregation tests, as well as the search for surface and latent defects of railway products, which are characterized by the right durability properties and fatigue resistance, were elements work-

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ing under dynamic load, namely: wheelset axle pivot, 60E1 profile railway rail, tyre raw forging and screw coupler elements i.e. shackle, coupling link, screw and coupling hook pin. The chemical constitution of the tested railway elements is shown in Tables 1 and 2. It is consistent with recommendations of the respective standards for the steel grades, which are mentioned.

2.1. Performing the Baumann test

The Baumann test is, in principle, performed on the product cross-section. Performing the Baumann test requires appropriate preparation of the product tested surface by turning or milling, then grinding and cleaning from contaminations, including defatting of the tested surface. Then a sulfuric acid solution is prepared (3–5) cm^3 in 100 cm^3 of distilled water, as is black and white bromine photographic paper, as well as a photographic fixing agent, namely sodium thiosulfate solution. The photographic paper, of a size adequate for the tested surface, should be immersed for approximately 5 minutes in the sulfuric acid solution. After filtering off the solution surplus, the photographic paper is placed with the emulsion coated side on the tested surface, simultaneously pressing the paper to the surface using a rubber roller, thereby causing air bubbles and solution drop disposal. As a result of reaction of the sulfuric acid acting on sulfides present on the product surface, precipitation of the hydrogen sulfide takes place, which reacts with silver bromide contained in the light sensitive emulsion, causing the appearance of dark points on the photographic paper generated by silver sulfide. The chemical reaction progress is the following [11]:

$$MnS\ (FeS) + H_2SO_4 \rightarrow MnSO_4\ (FeSO_4) + H_2S, \quad (1)$$

$$H_2S + 2AgBr \rightarrow Ag_2S + 2HBr. \quad (2)$$

In order to preserve the sharpness of the obtained presentation of sulfur segregation and latent defects of the tested element, Baumann prints undergo fixation in a photographic fixing agent, which is a 15–20% solution of the sodium thiosulfate.

Table 1

Chemical constitution of the wheelset axle, rail and wheel tyre

Sample / steel grade	Chemical constitution [%]											
	C	Mn	Si	P max	S max	Cr max	Ni max	Cu max	Mo max	V max	0_2 ppm	H_2 ppm
axle/P35G	0.34	0.76	0.15	0.035	0.015	0.11	0.05	0.053	0.006	0.003	122	0.6
PN-91/H-84027/03 grade P35G	max 0.37	max 1.10	max 0.45	max 0.035	max 0.035	max 0.30	max 0.30	max 0.30	max 0.05	max 0.05	–	–
rail/R260	0.73	1.05	0.47	0.015	0.011	0.08	0.04	0.05	0.01	0.01	18	1.7
PN EN 13674-1 grade R260	0.60 0.82	0.65 0.1.25	0.13 0.60	0.030	0.030	≤0.15	Al max 0.004	–	N max 0.010	0.030	max 20	max 2.5
tyre/P55A	0.57	0.82	0.27	0.013	0.008	0.06	0.03	0.05	0.006	0.003	13	0.4
PN84/H-84027/06 grade P55A	0.57 0.65	0.60 0.90	0.15 0.40	0.035	0.035	0.30	0.30	0.30	0.08	0.05	–	max 2.5

[Own work]

Table 2

Chemical constitution of the elements of the screw coupler 850 kN

Coupling elements / steel grade	Chemical constitution [%]										
	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	Al	Sn
shackle / 42CrMo4	0.41	0.69	0.24	0.008	0.014	1.05	0.15	0.21	0.16	0.023	0.012
coupling link / 41Cr4	0.41	0.77	0.24	0.013	0.004	1.05	0.09	0.22	0.03	0.019	0.021
screw / 41Cr4	0.42	0.74	0.22	0.012	0.030	1.02	0.14	0.18	0.04	0.022	0.013
coupling hook pin / 41Cr4	0.43	0.65	0.22	0.017	0.010	0.93	0.17	0.26	0.06	0.020	0.014
PN-EN 10083-3:2006 grade 41Cr4	0.38 0.45	0.60 0.90	max 0.40	max 0.025	max 0.035	0.90 1.20	–	–	–	–	–
PN-EN 10083-3:2006 grade 42CrMo4	0.38 0.45	0.60 0.90	max 0.40	max 0.025	max 0.035	0.90 1.20	–	–	0.15 0.30	–	–

[Own work]

3. Test results

Baumann tests were performed according to the above requirements on the cross-sections of the wheelset axle, rail, raw wheel tyre and elements of the screw coupler named as 850 kN. Baumann prints are shown in Figures 1–7.

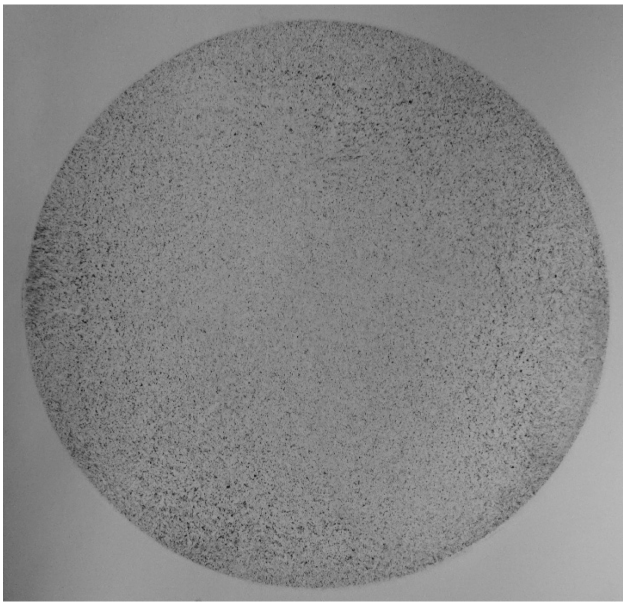

Fig. 1. Presentation of the sulfur segregation on the cross-section of the wheelset axle pivot with diameter 130 mm [own work]

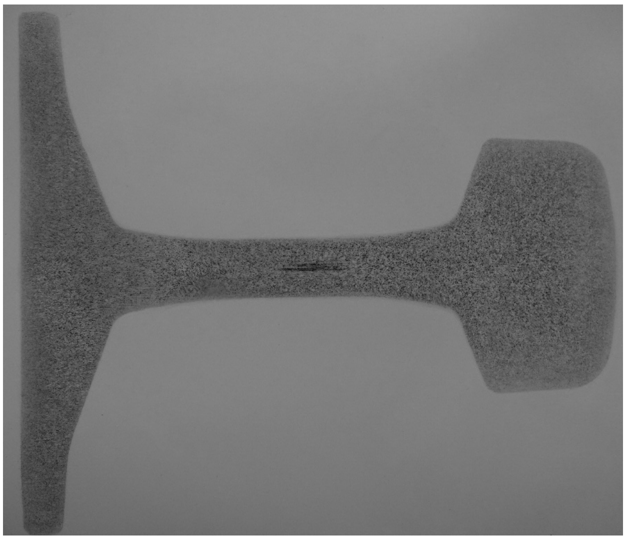

Fig. 2. Baumann print of the cross-section of a rail with the 60E1 profile [own work]

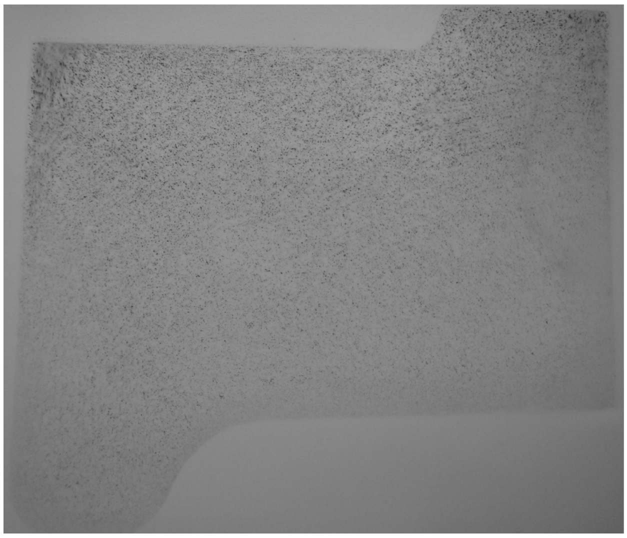

Fig. 3. Baumann print of the cross-section of wheel tyre Ø920 [own work]

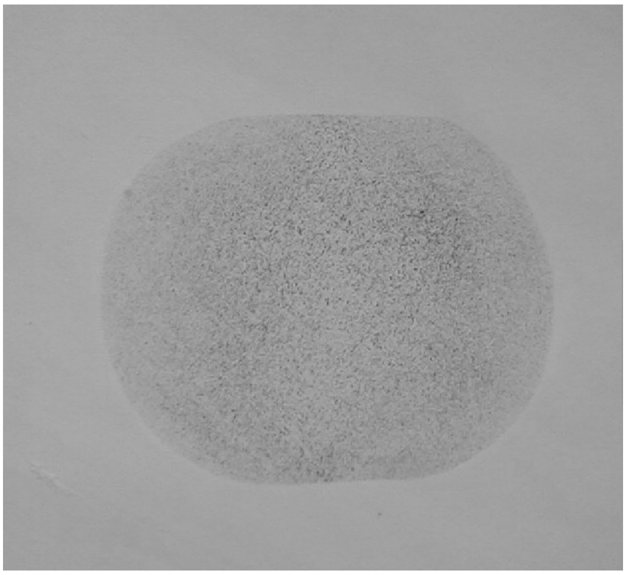

Fig. 4. Presentation of the sulfur segregation on the cross-section of a coupling shackle – Baumann print [own work]

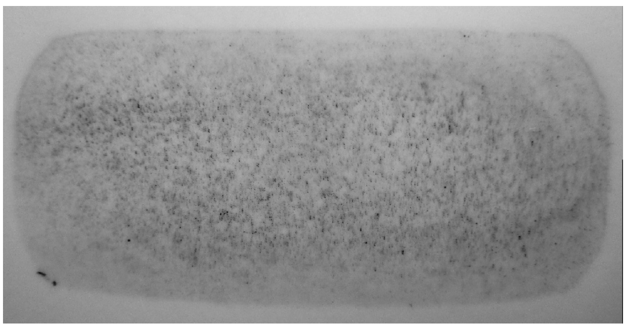

Fig. 5. Presentation of the sulfur segregation on the cross-section of a coupling link – Baumann print [own work]

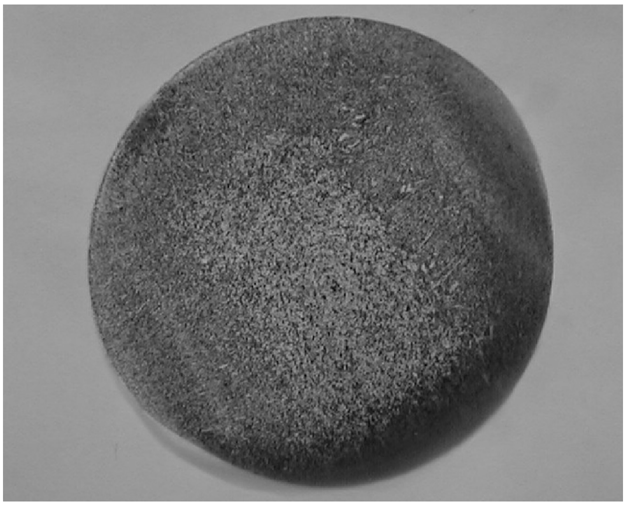

Fig. 6. Presentation of the sulfur segregation on the cross-section of a coupling screw – Baumann print [own work]

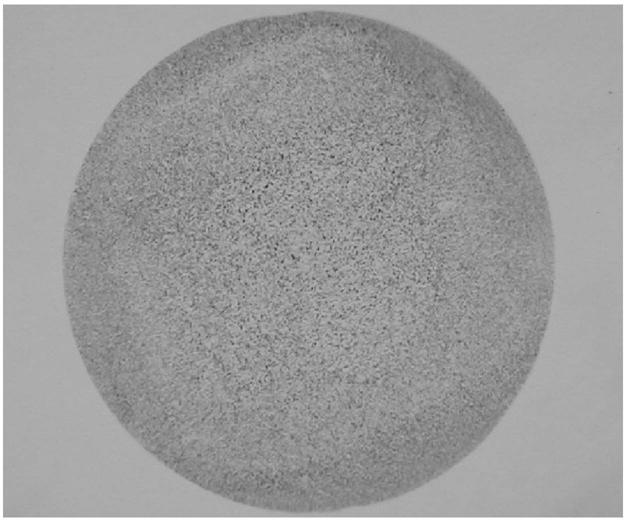

Fig. 7. Presentation of the sulfur segregation on the cross-section of a coupling hook pin – Baumann print [own work]

Presentation of the sulfur segregation is shown in Figures 1–3 respectively for the axle pivot, rail and tyre. Sulfur segregation on the tested intersection surfaces is tolerably uniform. Small liquation squares can be observed on the wheelset axle pivot print (Fig. 1) and on screw coupler elements i.e. coupling hook pin and coupling screw (Figs. 6 and 7). In addition, natural increased sulfur content in tyre inner areas and in the web of the rail can be observed (Figs. 2 and 3). This is caused by the concentration of the non-metallic inclusions during steel solidification in the central part of the continuous casting (COS). At the same time, no defects in the form of remains of the shrink hole, inner cracks caused by plastic forming and residues of the near-surface bubbles can be observed in the figures. However, presentation of the Baumann prints in Figures 4–6 points out increased sulfur segregation in the central part of elements of the screw coupler and changes in the material structure, which suggests heterogeneity of durability properties of the coupler elements. In contrast, no defects in the form of inner cracks or residues of the near-surface bubbles or a large concentration of non-metallic inclusions were observed on the intersections of the coupler elements.

4. Conclusions

Testing sulfur segregation with the Baumann test in railway elements working under dynamic load permits the quality assessment of those elements from the perspective of the sulfur distribution on the cross-section and the presence of latent product defects. It was ascertained that there is a natural sulfur segregation in railway elements with increased sulfur segregation in the central part of the product, and that the presence of liquation squares in large elements made of ingots, i.e. in railway axles and coupling hook pins and in screws of the screw couplers 850 kN, can be observed. The above-mentioned defects can cause the heterogeneity of durability properties in the bulk of railway products. No internal defects in the form of cracks of the tested railway elements were observed.

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